BENTHIC MACROFAUNA-SUBSTRATE RELATIONSHIPS IN AN UNPOLLUTED AND A POLLUTED STREAM ENVIRONMENT

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ABSTRACT

Current velocity, substrate and macrofauna at three polluted and three unpolluted stone-substrate sites in the Kaiapoi River, Canterbury, New Zealand (43°23'S, 172°37'E) were compared. A bimodal particle size distribution of sediments was found. The two predominant size classes (0.25 mm - 0.50 mm, and 16 mm - 64 mm diameter) are described by widely-used indices derived from cumulative frequency curves. Substrate differences between stations were too small for there to be detectable differences in the associated macrofauna. In some unpolluted substrates, organic matter levels were comparable with those in polluted substrates. Under such conditions some organisms characteristic of polluted benthos occurred at "clean" stations. Tubificidae, the most widely distributed group, occurred at all stations in the substrate between the surface and 120 mm. Larvae of Ephemeroptera and Trichoptera occurred at all unpolluted stations, while larvae of *Chironomus zealandicus* (Chironomidae) occurred at all polluted stations.

The colonisation of substrate within containers set into the stream bottom was examined. Container effects are discussed. Changes in macrofauna in containers transferred between polluted and unpolluted stations are interpreted by considering tolerance to water quality changes, and exit and entry of organisms. Organisms absent from polluted benthos, e.g. Ephemeroptera and Trichoptera larvae, rapidly colonised enriched substrates transferred from polluted stations.

INTRODUCTION

The effect of an effluent on water quality depends on the kind and relative amount of the pollutant(s) present, and the physical and biological characteristics of the receiving water. Merely the presence or absence of an indicator species can be a misleading biological criterion of water quality (Gaufin and Tarewell 1952). A more reliable assessment is obtained by describing the composition of the whole aquatic community in relation to relevant environmental variables. Several studies have shown that substrate particle size, current velocity and distribution of food material are primary factors determining

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microdistribution of benthic invertebrates in unpolluted lotic systems (e.g. Cummins 1964, 1966, Cummins and Lauff 1969). Substrate particle size can also influence factors such as current velocity and food supply. Its central role in benthic ecology has been shown by marine (e.g. Sanders 1958), lake, and stream (e.g. Wene 1940, Cummins 1964, Eriksen 1963) studies. In this study the benthic macrofauna and substrate are examined in relation to the effect of a fellmongery effluent on a stream.

STUDY AREA

Six stations above and below an effluent discharge point (Fig. 1) were chosen along 1.8 km of the Upper Kaiapoi River (NZMS Sheet S76: 995728-002742; 43°23'S, 172°37'E), a small tributary of the Waimakariri River. The Kaiapoi River, known before 1960 as the North Branch of the Waimakariri River, arises from small springs about 7 km west of the study area, and flows through farmland throughout its length. Thus, even the section designated unpolluted in this study is modified to some extent by agricultural runoff. Biological and chemical surveys of this river are included in several reports (Ministry of Works and Health Department Report 1956, Hirsch 1958, Dalmer 1971, Winterbourn, Alderton and Hunter 1971, Toshach 1976) and my study area included three of Hirsch's stations (Fig. 1). The source of the effluent, a fellmongery (wool scour) draws and discharges water only during an eight hour day, five day week. The discharge consists of an intermittent flow of diluted chemicals used in the scour process, viz. sodium sulphide, lime, sulphuric acid and detergent; and organic material, including: wool, fats and blood. During 1974-75 a plant was installed to treat these wastes, and Toshach (1976) studied biological and chemical changes in the river after removal of most of the wastes.

All sampling stations selected had similar stony beds. Stations 1, 2 and 3, and stations 5 and 6 were separated by deep, soft bottom stretches, whereas stations 3, 4 and 5 were separated by stony riffles. Between stations 3 and 4 a weir deepened the river sufficiently for the fellmongery to draw its water requirement. Stream width at the six stations ranged from 14 m to 18 m, and maximum depth ranged from 0.2 m to 0.5 m (Table 1). The effluent entered the river between

TABLE 1. STREAM WIDTH, DEPTH AND CURRENT VELOCITY AT EACH STATION. MAY 1971.

Station	Stream width (m)	Max. depth (m)	Mean current velocity (m/sec)
1	16	0.36	0.36
2	17	0.30	0.40
3	18	0.48	0.22
4	17	0.32	0.40
5	14	0.24	0.72
6	18	0.41	0.28

METHODS

Macrofauna and substrate samples were collected using a steel corer. Cores (100 mm - 120 mm long, 60 mm diameter) were extracted by tilting the corer slightly after it had been driven into the stream bed, and sealing the bottom with the palm of the hand before lifting it to the surface. Before the hand seal was released, water overlying sediment in the corer was siphoned through a plastic tube into a sorting tray. This prevented water from running through the core displacing fine sediment or loose epifauna. The core was extruded into a trough and divided into four 30 mm - 40 mm lengths (layers a, b, c and d) for separate examination. Large stones were removed by wet sieving each layer through a 49 mm square-mesh sieve. The remainder of each layer was hand sorted in diluted subsamples, and all macroinvertebrates were removed, identified and counted. The sediment was then left to settle for three days, after which the water was decanted off and the sediment analysed for particle size and organic matter content (Appendix).

Current velocity was measured at four equidistant points across the stream at each station, using a modified Pitot tube held 50 mm above the stream bed.

An enclosed sediment core was placed in the stream bed at each station to examine the effects of effluent on a macrofauna community. Round plastic pots, 100 mm deep by 120 mm diameter were filled with sediment from the sites where they were to be placed. The natural bed stratification was simulated as closely as possible. In a preliminary experiment to determine container effects and colonisation, uncovered pots were buried in the stream bed with their tips level with the surrounding substrate surface to minimise erosion effects. In subsequent tolerance experiments pots were removed after one week and covered with 1 mm square-mesh netting before being replaced.

RESULTS AND DISCUSSION

Sediment Description

Cummins (1962, 1966) outlined recommendations for the presentation of sediment data in stream ecology studies, and these have been followed where possible. Standard procedures used in sedimentary geology (e.g. Twenhofel and Tyler 1941) provide the basis for the sediment analysis techniques and the presentation of data.

There are few experimental studies of invertebrate-substrate relationships (except Cummins and Lauff 1969) on which to base a choice of sediment size classes which are meaningful in terms of the macrofauna present. The Wentworth scale of sediment sizes was used in this study, and in modified form (Fig. 2), it may be of ecological significance (Cummins 1962). Stream sediments may comprise a wide range of particle sizes and different species preferences for particular size categories make it very difficult to describe statistically

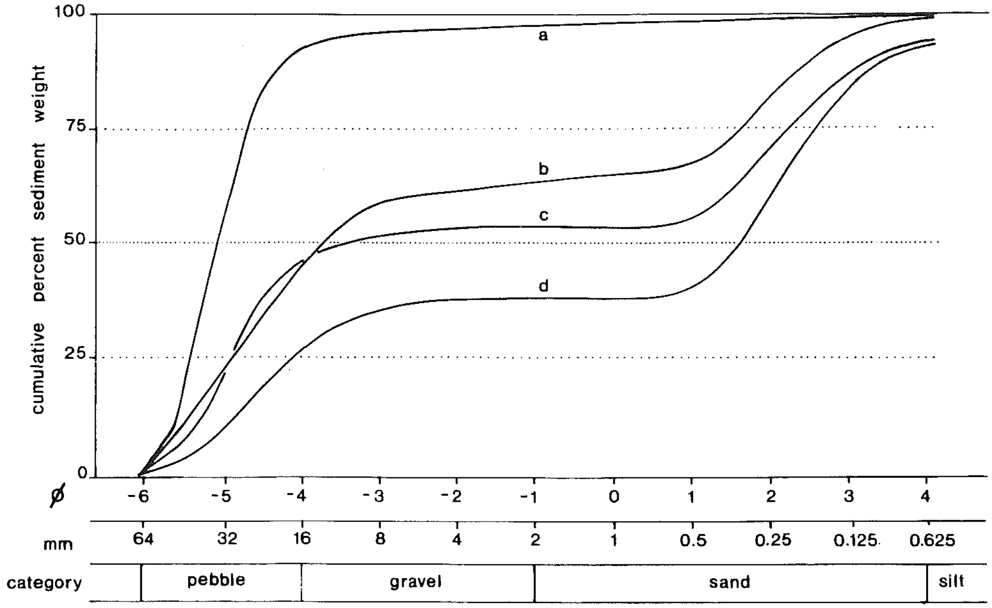

Fig. 2. Particle size distribution in layers a, b, c and d of a core from station 1. All the cores described a similar curve when plotted in this way on semi-log paper. The steeply sloping section of the curve corresponds to the predominant sizes while the plateau indicates an absence of intermediate sizes. Phi ($\phi=-\log_2\xi$ where ξ = particle diameter in mm), diameter (mm), and modified Wentworth categories (after Cummins 1962) are shown.

the sediment data for simplified comparison of cores, and yet retain sufficient detail for ecological interpretation. For example, the presence of small amounts of silt-clay may have little effect on the statistical description of the sediment, but may determine the suitability of that habitat for a particular species.

In this study the silt-clay fraction was not sub-divided. For each of the four sediment layers a cumulative frequency curve was constructed. Each point on the curve represents the total percentage weight of the sample which would be retained if only that sieve were used. The cumulative frequency curves all showed a bimodal form (Fig. 2) and the dominant size classes were medium sand (0.25 mm - 0.50 mm), and pebble (16 mm - 64 mm). These two fractions are characteristic of the lower Waimakariri flood plain where quite well sorted (i.e. narrow size range) stony layers are found adjacent to sands and silts of alluvial, loessial, and prograded beach ridge origin (Vucetich 1969, R.M. Kirk, Geography Department, University of Canterbury, pers. comm.). The relative absence of coarse sand and gravel may also reflect the weathering characteristics of greywacke, which may not produce these size classes. Using the median diameter alone to describe these curves (Fig. 2), stresses either the sand fraction (layer d), or the pebble fraction (layers a, b, c), depending on whether the intermediate plateau falls above or below the 50% line, and neglects the other predominant fraction. Because both of these fractions are important to the macrofauna community, they have been considered individually. The fractions were divided at 2 mm diameter because this defines the upper limit of coarse sand in the Wentworth scale, and it is in the size range which is absent consistently from the samples. The <2 mm fraction is not only important as habitat for burrowing infauna, but as a food source and case-building material for epifauna. The >2 mm fraction provides attachment and shelter for epifauna, and by its packing arrangement it determines the available space and the stability of the interstitial fine sediment for the infauna.

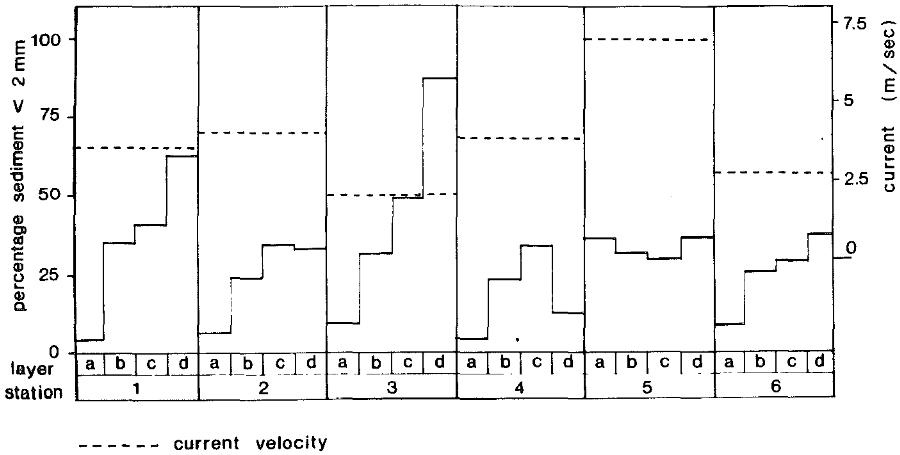

Fig. 3. Fine sediment (<2 mm) as a percentage of the total sediment of each layer, at stations 1-6, shown with current velocity (m/sec) measured 0.05 m above the sediment. Note right-hand ordinate.

The percentage of fine fraction in each core layer is considered in relation to current velocity (Fig. 3). Current velocity was lowest at station 3 (0.22 m/sec) and highest at station 5 (0.72 m/sec). As all stations had stone bottoms, the lowest current velocity recorded was presumably still too high for the mass deposition of fine particles. In fact, the highest percentage of fine particles in upper layers occurred at station 5, which had the highest current velocity, but where waste fibrous material from the effluent and "sewage fungus" formed a mat which acted as a silt trap. With this exception, the percentage of fine particles in each layer increased with depth as the erosive effect of the current declined. The very high percentage of fine particles in layer d, station 3, was the result of a subsurface layer of dead sticks, under overhanging willows, which had trapped fine sediment particles before becoming covered with pebbles.

Cumulative frequency curves were constructed for sediment greater than 2 mm and less than 2 mm diameter for each layer (e.g. station 1, Fig. 4). From these curves, the median

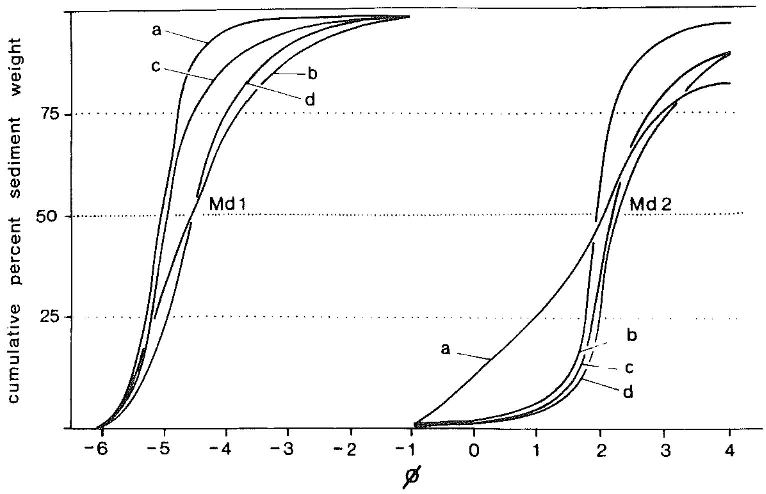

Fig. 4. Particle size distribution of layers a, b, c and d of the core from station 1 (Fig. 2) after separation of the <2 mm and >2 mm size fractions. The large fraction is described by the 50 cumulative percent level (Md1) while the fine fraction is described by the 75, 50 and 25 cumulative percent levels (first, median (Md2), and third quartiles respectively).

quartiles (Md1 and Md2) were calculated for each fraction (Fig. 5). The degree of sorting is shown by the range of particle sizes between the first and third quartiles. Generally the degree of sorting increased with increasing current velocity and turbulence. Layer a was very well sorted at station 1, but at station 2 it was the least sorted layer, and at the other stations it was not markedly better sorted than deeper layers. Station 5, with the highest current velocity was well sorted at all depths. Md1 for layer a ranged from 15 mm - 33 mm pebbles, reflecting the gross similarity of the bottom at each station, which was the criterion by which stations were selected. There was little change with depth, although the lowest values of Md1 occurred in layer d at stations 3, 5 and 6. Md2 did not vary greatly between layers or between cores. At station 2, clay between the pebbles produced a very low value of Md2.

Organic Carbon

The results of the Walkley and Black partial oxidation of organic matter by chromic acid (Appendix) vary significantly according to the nature of the substrate analysed (Cummins 1962). In this study all samples were of a similar substrate type and carbon values obtained by wet oxidation were used to compare them (Fig. 5). Organic carbon was generally higher in the cores from stations 3-6, although layer a, station 1, had a value second only to layer a, station 4. Deciduous willow trees overhang stations 1, 3, 5 and 6, and at stations 1 and 3 dead leaves occurred in layer a. At station 3, dead sticks occurred just beneath

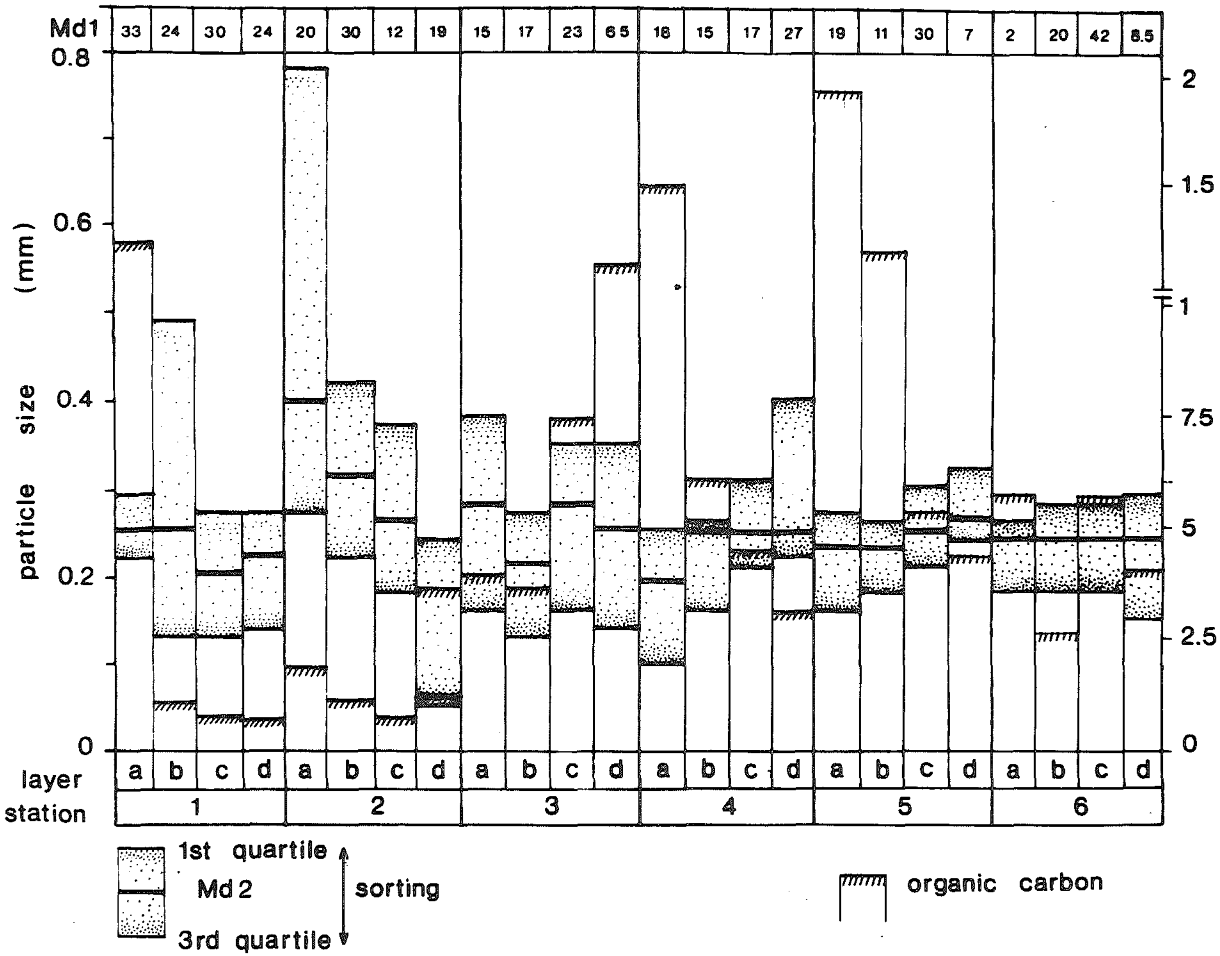

Fig. 5. Sediment particle size for each core layer, described by the parameters Md1 (top row) for the >2 mm fraction, first, median (Md2) and third quartile, and the degree of sorting (stippled area) for the <2 mm fraction. Organic carbon for each layer is shown as a percentage of the fine fraction.

the surface of the bed. At stations 4 and 5, where carbon values declined with depth, layer a consisted of a mat of wool fibres which trapped the organic and silt particles.

In this study local natural sources and effluent seemed to affect organic carbon levels much more than sediment particle size, and equally high levels of organic material occurred in both natural and polluted situations. The lower layers of cores from stations 3-6 however, were noticeably more anaerobic, being black and odorous.

Macrofauna

Epifauna and infauna (Fig. 6) are considered separately as numbers per 100 g total substrate, and numbers per 100 g fine sediment (less than 2 mm) respectively. Ephemeroptera (mainly *Deleatidium* spp.) and Trichoptera (*Oxyethira, Pycnocentria,* and *Hydrobiosis*) larvae were found only in layer a at stations 1 and 3, but general collecting showed them to be present also at station 2 and the unpolluted west side of station 4. The molluscs, *Physa* sp. and *Pisidium* sp. were found in low numbers in the upper layers of cores from stations 1 and 2. The most abundant mollusc, *Potamopyrgus antipodarum* occurred at stations 1, 2, 3 and 5. Its highest numbers were in layer b, except at station 3 where, with a low current velocity, large numbers were observed feeding on exposed upper sides of stones. None of these molluscs occurred in layer d at any station.

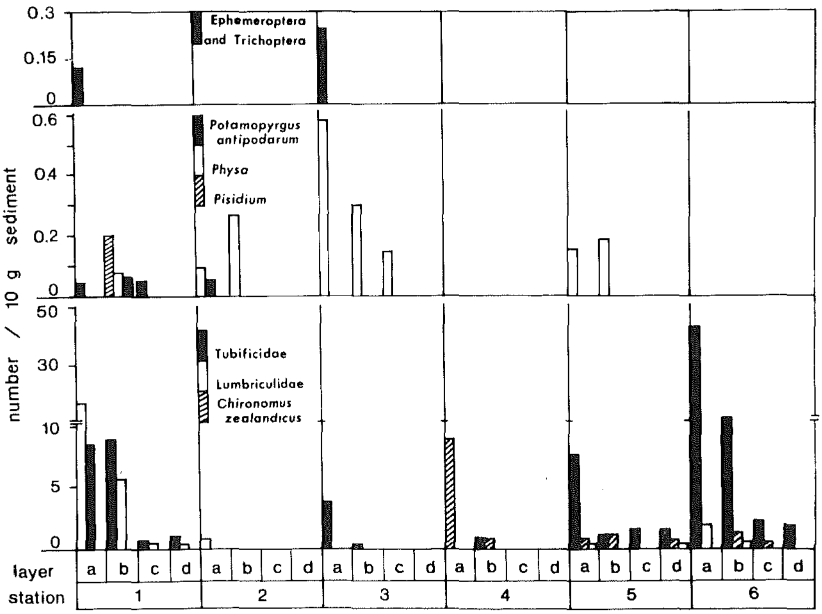

Fig. 6. Numbers of the main species and groups, per 10 g total sediment for Ephemeroptera, Trichoptera and Mollusca, and per 10 g fine fraction (<2 mm) for the burrowing worms (lower graph), in the cores from stations 1-6.

Oligochaetes (Tubificidae and Lumbriculidae) were present at all stations and depths. Their highest numbers occurred in layers a and b at stations 1, 5 and 6. Tubificids were the most common macrofaunal group, occurring at all stations except station 2. Their absence in layer a, station 4 coincided with a high population of *Chironomus zealandicus* larvae. In layer a, station 6, the highest tubificid population (over 400 individuals per 100 g fine sediment) occurred, in the absence of *C. zealandicus*. In the subsequent container experiment (Fig. 9), however, the container at station 6 was colonised by high numbers of both organisms. *C. zealandicus,* a burrowing dipteran larva, occurred only at the polluted stations, and was the only macrofaunal occupant of the rich organic layer a at station 4.

Other macrofauna occurring infrequently included Crustacea (*Paracalliope fluviatilis* and Ostracoda), and platyhelminthes (*Dugesia, Cura pinguis, Glossiphonia* sp. and *Prorhynchus putealis*).

CONTAINER EFFECTS ON SEDIMENT AND MACROFAUNA

Containers which had been in position at each station for a week were removed and divided into layers a, b and c (each 20 mm - 40 mm deep). Analysis of particle size and organic content showed that there were differences between containers and cores. When the layers in each container were combined, the silt-clay fraction constituted a lower percentage of the total sediment at each station than in the cores (Fig. 7). Md1 showed a similar range in the cores and containers (Figs. 5,8) but was generally higher in layer a of the container indicating that the gravel of this large fraction was removed from the upper layer leaving the heavier pebble grade. The fine fraction showed a more erratic Md than in the cores and was reduced to silt-clay size in layer a at stations 1, 2 and 6 (Fig. 8). There was a general trend towards increasing Md2 with depth, which was not apparent in

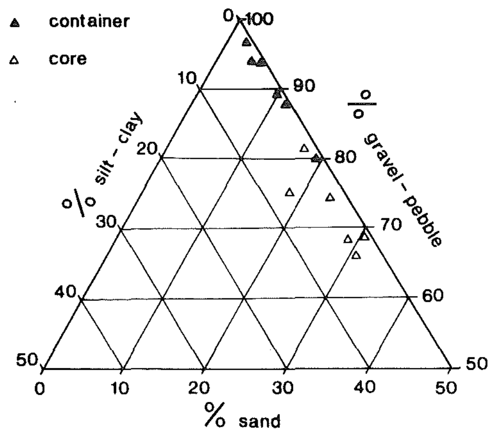

Fig. 7. Relative percentages of pebbles and gravel (>2 mm), sand (2-0.0625 mm) and silt-clay (<0.625 mm) in the core and container sediment samples.

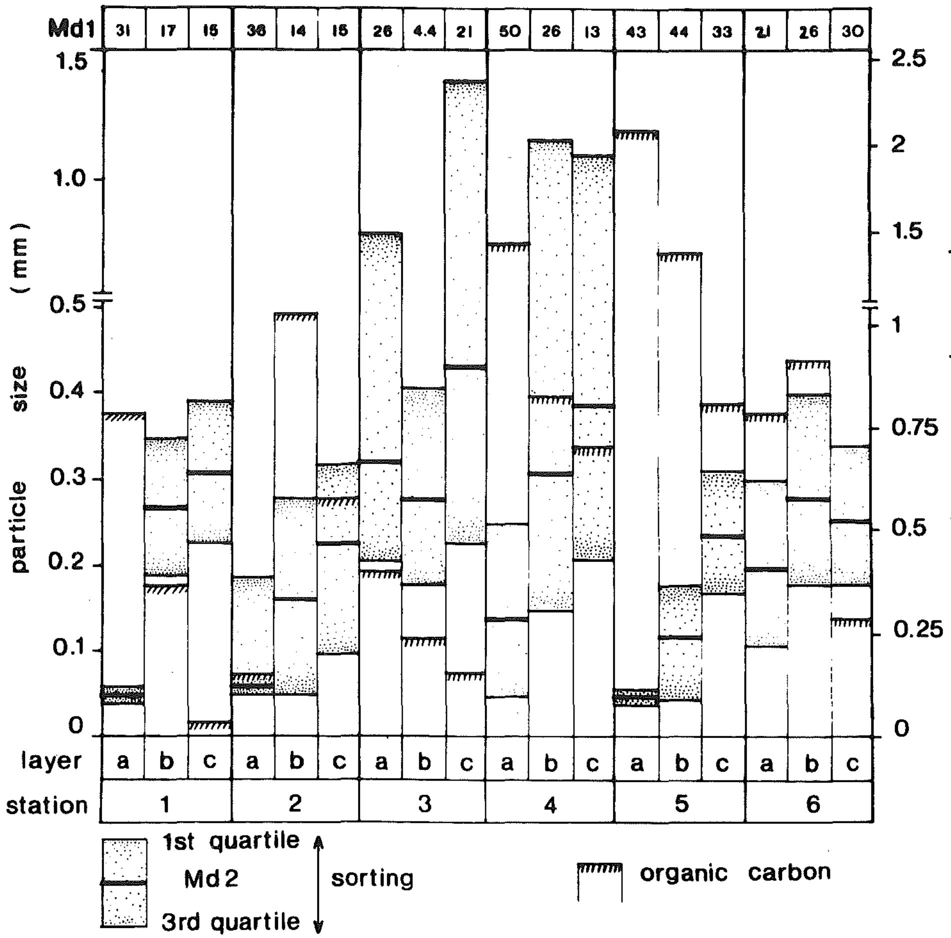

Fig. 8. Sediment particle size of each container layer described by the parameters Md1 for the >2 mm fraction, and first, median (Md2) and third quartiles and degree of sorting (stippled area) for the <2 mm fraction. Organic carbon for each layer is shown as a percentage of the fine fraction.

the cores. This suggests that the container induces turbulence effects which remove sand from layer a, either into the stream or down into layers b and c, and deposits finer particles in the upper layer. Silts and clays may be more resistant to erosion than sand because of strong cohesive forces, although once entrained they can be kept in the water column by lower velocities than sand grains (Morisawa 1968). The degree of sorting in the containers was more closely related to current velocity than in the cores. At stations 1, 2, 4 and 5, which had the highest current velocities, the highest degree of sorting occurred, along with the lowest Md2 in the upper layers. Station 3, with the lowest current velocity, showed poor sorting and a high Md in all layers. This greater influence of current on substrate parameters in the containers is expected as the substrate is less compacted, and eddy currents may be generated within the container.

The initial arrangement of sediment in the containers may have also differed from the cores, as any disturbance of the stream bottom causes some change in the fine fraction. It is not known whether a stable sediment will consolidate in a container, and one week may have been too short a period to examine this process.

Amounts of organic material in containers at all stations generally exceeded those occurring in cores (Fig. 8). An exception was found at station 3 where the layer of dead sticks in the core was not duplicated in the container. Containers trapped large quantities of organic material at the polluted stations, demonstrating the continual daily input of material, whereas the accumulation of leaves at the cleaner stations would be expected to decrease during winter after an autumn maximum.

The fauna colonising the open containers after one week at each station (Fig. 9) was similar to that in cores at the respective stations, although epifauna and infauna generally occurred in higher numbers at deeper levels in the less compacted container sediment. *P. antipodarum* occurred in all containers, and again was most abundant in the upper layers of station 3. *Pisidium* and *Physa* occurred in containers at all stations, whereas they only occurred in the cores at stations 1 and 2. This may reflect the greater size of sample in the container (container 120 mm diameter, cf core 60 mm diameter). Oligochaetes did not occur in such high numbers in the upper layers of station 1 container as in the core, but patterns were similar for cores and containers at polluted stations, although much higher numbers of tubificids colonised the lower layers of the container at station 6. Station 5 had fewer infaunal burrowers, and *P. antipodarum* than stations 4 and 6. This may reflect a greater current effect in the station 5 container where current velocity was highest.

CONTAINER TRANSFERENCE EXPERIMENT

Methods

Two containers of sediment were set up at station 3

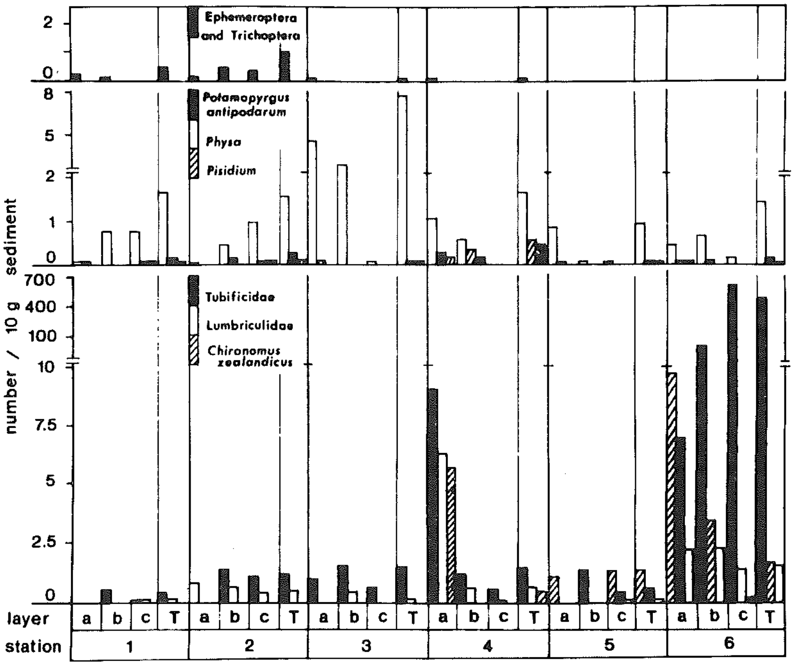

Fig. 9. Numbers of the main species and groups, per 10 g total sediment for Ephemeroptera, Trichoptera and Mollusca, and per 10 g fine fraction (<2 mm) for the burrowing worms (lower graph), colonising the containers placed at stations 1 to 6 for one week.

(pots 1,2), and 6 (pots 3,4). After one week, pots 1 and 3 were removed from the stream and the macrofauna in the layers counted, and replaced with the substrate in as near to the original arrangement as possible. Pots 2 and 4 were not disturbed in this way. All four pots were covered with 1 mm mesh to minimise subsequent exit and entry of macrofauna. Pots 1 and 2 were transferred to station 6, and pots 3 and 4 to station 3. One and two weeks later pots 1 and 3 were removed, the macrofauna in each layer was counted, and the pots were replaced within 6 h. After four weeks all pots (1-4) were removed from the stream. The pair of pots at each station provide a comparison of disturbed and undisturbed contents 4 weeks after transference to a station of contrasting water quality (Fig. 10).

Results

1. Transference of pots from unpolluted (station 3) to polluted (station 6) water.

Ephemeroptera and Trichoptera died in less than one week. Numbers of *P. antipodarum* in layer a did not change, but none were found in layers b and c. Total numbers were lower than those in the pot transferred from station 6 to station 3.

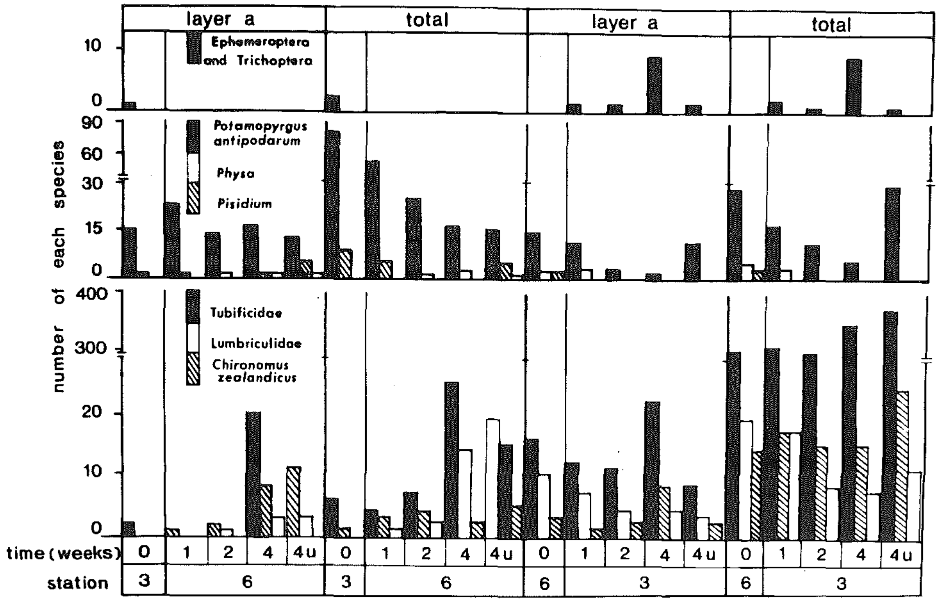

Fig. 10. Changes in the numbers of each of the main species and groups in layer a and in the total containers transferred between station 3 (unpolluted) and station 6 (polluted), before transference (0), and after 1, 2 and 4 weeks. 4u indicates the undisturbed container examined after 4 weeks.

Pisidium seemed to be susceptible to disturbance, but maintained its numbers in the undisturbed pot. *Physa* colonised the pots between the second and fourth week after transference, while numbers of infaunal burrowers increased after the first week. Numbers of *C. zealandicus* larvae increased from the first week, and at an increased rate during the last two weeks when a layer of organic material had accumulated under the mesh, to reach the density of the original pots from station 6 by the fourth week. More tubificids colonised the disturbed pot than the undisturbed one, whereas the colonisation rate of lumbriculids was slow and levelled off after two weeks.

2. Transference of pots from polluted (station 6) to unpolluted (station 3) water.

The disturbed container was colonised rapidly by Ephemeroptera and Trichoptera after the second week. Decrease in numbers of *Physa* and *Pisidium* probably resulted from random movements out of the container as no dead individuals were found, and both species occurred naturally at station 3. Tubificids increased in numbers in all layers after the second week, while lumbriculids only increased in layer a. Numbers of the three infaunal species were higher in the undisturbed pot after the four weeks. *Chironomus zealandicus* decreased markedly in numbers in all layers, and dead individuals were removed each week. *C. zealandicus* was not found at any of the unpolluted stations in the study, but during general collecting it was found at deep, soft bottom (fine sediments rich in naturally occurring organic material) sites between stations 1, 2 and 3.

The results obtained in this experimental study indicate that some species rapidly colonised new sediment with a history of different water quality (Table 2), while other species were unable to tolerate such a change in water quality. Tubificids were unique in their increase in both situations. They were able to exploit an environment rich in both oxygen and organic material.

TABLE 2. CHANGES IN TOTAL NUMBERS IN THE DISTURBED CONTAINER 4 WEEKS AFTER TRANSFERENCE TO A DIFFERENT WATER QUALITY.

	Unpolluted → Polluted	Polluted → Unpolluted
Ephemeroptera, Trichoptera	-	+
Potamopyrgus antipodarum	-	-
Physa sp.	+	-
Pisidium sp.	0	-
Tubificidae	+	+
Lumbriculidae	+	0
Chironomus zealandicus	+	-

- = decrease; 0 = unchanged; + = increase

Although the pots were covered with 1 mm mesh so that tolerances of a confined community could be examined, migration was not eliminated. A finer mesh would have been too susceptible to blocking thus creating a "mesh" effect in addition to container effects. Nevertheless the experiment showed that such an approach can provide data to supplement a field survey of macrofauna-pollution relationships. Although the study was confined to single samples from each station, the results suggest possibilities for further useful research in substrate-macrofauna relationships, and the utilisations of different organic matter sources under different current-oxygen regimes.

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APPENDIX: Sediment particle size and organic carbon analysis.

1. Substrate sample wet sieved 1 mm sieve, Fraction 1: greater than 1 mm
   Fraction 2: less than 1 mm

2. Fraction 1: Dried, 1 week, 50°C.
   Sieved: 64 mm, 32 mm, 16 mm, 7.9 mm, 4.7 mm, 2 mm, 1 mm, less than 1 mm.
   Weighed to 0.01 g.

3. Fraction 2: Mixed, two subsamples: a) 20 g, particle size
   b) teaspoonful, organic C.

4. Subsample a):

   50 ml H_2O_2, 24 h, darkness, to remove organic material.
   Organic scum, H_2O_2 decanted off.
   Wet sieved, 0.06% Calgon (dispersant) using 0.063 mm sieve.
   Greater than 0.063. Dried, 1 week, 50°C.
   Sieved: 1 mm, 0.5 mm, 0.25 mm, 0.105 mm, 0.063 mm, less than 0.063 mm.
   Less than 0.063 mm fractions pooled, dispersed in measuring cylinder and immediately subsampled by 25 ml pipette at 0.1 m depth.
   25 ml sub-sample dried 36 h, 50°C, cooled desiccator.
   All fractions weighed to 0.001 g.
   All sieves: square mesh Endecott.
   All sieving using a shaker pre-set at 30 min.

5. Subsample b):

   Fine ground in mortar, 2 g weighed into clean bottle, oven dried 100°C, 2 h.
   Cooled in desiccator, weighed to 0.0001 g.
   The sample was then analysed for organic carbon using the Walkley and Black method as described by Morgans (1956).